STATUS REPORT ON THE NASA GRANT NGR-39-007-011

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In this report the status of the research on the crack propagation in cylindrical shells, which is supported by a grant from the National Aeronautics and Space Administration (NGR-39-007-011), is reviewed. The completed portion of the program is summarized and a brief outline of the work which is currently in progress is given.

1. Summary of Completed Work

In broad terms, the basic objective of the present research program was:

> To develop a rational theoretical basis of comparison between fatigue crack growth characteristics in thin plates under plane extension and that in structures composed of thin plates and shells under arbitrary external loads; to carry out the necessary theoretical studies and to perform the necessary experiments for the development and the verification of a suitable model.

The completed portions of the research have been reported to NASA as technical progress reports (sec references 1-12). In this phase of the program, the emphasis was on the investigation of the effects of two factors on the fatigue and fracture of thin plate and shell structures, namely, the shell curvature and the load condition (i.e., the combined membrane and bending loads, torsion, biaxial membrane loads, and other combinations).

The problem of fatigue crack propagation in plates subjected to cylindrical bending was studied in [1]. The effect of mean stress on the fatigue crack growth rate was studied in [4], [5], and [9]. In these studies, the stress intensity factor was used as a correlation parameter to analyze the results.

The results of fatigue crack propagation studies in cylindrical shells were reported in [7], [10] and [12]. The shell results were also analyzed by using the stress intensity factor as the correlation parameter. Thus, since the problem of fatigue and fracture in cylindrical shells was an important part of the research project, a rather extensive program was undertaken to study the stress distribution in shells containing straight cracks, and specifically, to evaluate the stress intensity factors for various kinds of load conditions. The completed part of these studies was reported in [11], where the stress intensity factors in cylindrical and spherical shells subjected to extensional membrane loads (e.g., internal pressure) and uniform bending were given. The main result of these studies was that even if the shell is subjected to pure membrane or bending load outside the perturbation zone of the crack, in the neighborhood of the crack tips the stress state is always combined membrane and bending.

Fatigue crack propagation results in 6063-T6 aluminum cylinders subjected to internal pressure were reported in [7], which also includes crack propagation model for combined bending and membrane loads, some details of the stress analysis, and the results of the static strain analysis around the crack tips. The results for the 6063-T6 cylinders subjected to fluctuating torque were reported in [10]. In the torsion experiments a circular hole on the cylinder wall was used as a stress raiser to initiate the fatigue cracks, which were formed and propagated along approximately two 45-degree helixes. Reference [12] contains the results for the 6061-T4 aluminum plate and shells. In [12] a direct comparison of the fatigue results in uniaxially loaded plates and internally pressurized cylinders of the same material and the same thickness was made. [12] also includes the results of some preliminary studies of the effect of load biaxiality on the fatigue crack propagation rate in and the rupture strength (i.e. plane stress fracture toughness) of thin plates. The tentative conclusions concerning the effects of load biaxiality in plates are that, a) there are two factors influenced by the load biaxiality which play a dominant role in the fatigue and fracture behavior of thin plates and shells. These factors are the plastic deformations around the crack tips and wrinkling or bulging of the plate (or shell) around the crack; b) at reasonably low fatigue crack growth rates (e.g., $da/dn \leq 10^{-3}$ in/cycle), the bulging or wrinkling is not signigicant and the plastic zone around the crack is small. Hence, at low crack growth rates the effect of stress biaxiality is not very significant, and in most cases the resulting deviations fall into the natural scatter band of the experimental data; c) for most crack sizes of practical interest the rupture stress in thin plates and shells is very close to the yield strength of the material; hence there is a considerable effect of load biaxiality on the bulging and plastic deformations around the crack. As a result of this the rupture strength (or the plane stress fracture toughness) of the material becomes very highly dependent on the stress biaxiality-increasing with the increasing ratio of the stress component which is parallel to the crack to that which is perpendicular to the crack.

The work reported in the references [2], [3] and [6] consisted of some related theoretical problems dealing with the elastic and elastic-plastic stress distribution in two-dimensional media of various geometries. Reference [8] dealt with the development of the basic analytical tool used in the theoretical solution of the shell problems.

2. Research currently in progress

Following is a brief description of problems which are currently being studied:

The investigation of the effect of stress biaxiality on the fatigue crack propagation rate and the rupture strength of thin-walled cylinders and plates is being continued. To change the stress ratio in shells, the feasibility of running the fatigue experiments with cylinders without the axial constraint is being studied (both the"closed" and "open" ends are being considered). The effect of the ratio of the principal stresses away from the crack on the rupture strength of thin plates is being studied in more detail. In these studies thin aluminum as well as plexiglas plates are being used to separate the effect of bulging as much as possible (in plexiglas there is no bulging).

With the exception of torsion case, in all the shell studies which have been discussed so far, the crack was located parallel to the axis of the cylinder. Another important practical case, however, is that of a cylindrical shell containing a circumferential crack (which may result from axial tension or bending of the whole cylinder with or without the internal pressure). The experimental work on this problem consists of the fatigue crack propagation rate and rupture strength studies in axially loaded cylinders containing a circumferential crack. The configuration has certain advantages, among which the following may be mentioned: a) The stress state away from the crack is uniaxial; b) at slow crack growth rates there is no bulging in the shell, and c) the test specimen can carry certain amount of compressive load-adding more flexibility to the test program. Thus, in comparing the results of these tests with that of uniaxially loaded plates, the only difference is expected to come from the shell curvature.

Other theoretical problems which are currently being studied are the evaluation of stress intensity factors in cracked cylindrical shells under anti-symmetric loading and the effect of a certain anisotropy on the stress intensity factors.

<u>References</u>:

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